US009304350B2

# (12) United States Patent
Yang et al.

(10) Patent No.: US 9,304,350 B2
(45) Date of Patent: Apr. 5, 2016

## (54) ENCAPSULATED POLYMER STABILIZED CHOLESTERIC TEXTURE LIGHT SHUTTER

(71) Applicant: **Kent State University**, Kent, OH (US)

(72) Inventors: **Deng-Ke Yang**, Hudson, OH (US); **Yue Cui**, Kent, OH (US); **Cuiyu Zhang**, Kent, OH (US)

(73) Assignee: **Kent State University**, Kent, OH (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 132 days.

(21) Appl. No.: **13/908,446**

(22) Filed: **Jun. 3, 2013**

(65) **Prior Publication Data**

US 2014/0160399 A1 Jun. 12, 2014

**Related U.S. Application Data**

(60) Provisional application No. 61/654,148, filed on Jun. 1, 2012.

(51) **Int. Cl.**

| | |
|---|---|
| ***G02F 1/1333*** | (2006.01) |
| ***G02F 1/1334*** | (2006.01) |
| *G02F 1/137* | (2006.01) |

(52) **U.S. Cl.**

CPC .... ***G02F 1/1334*** (2013.01); *G02F 2001/13775* (2013.01)

(58) **Field of Classification Search**

None

See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

| | | | | |
|---|---|---|---|---|
| 2011/0134372 A1* | 6/2011 | Lee et al. | ........................ | 349/88 |
| 2012/0088320 A1* | 4/2012 | Hwang et al. | .................. | 438/27 |

* cited by examiner

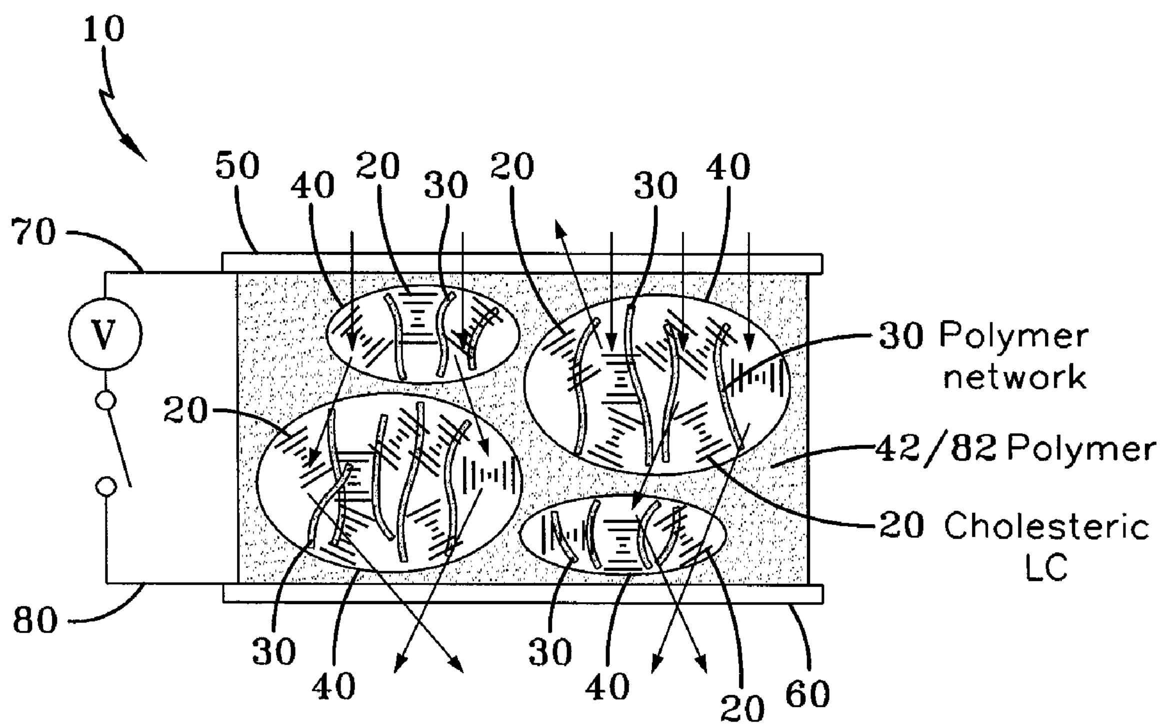
*Primary Examiner* — Richard Kim

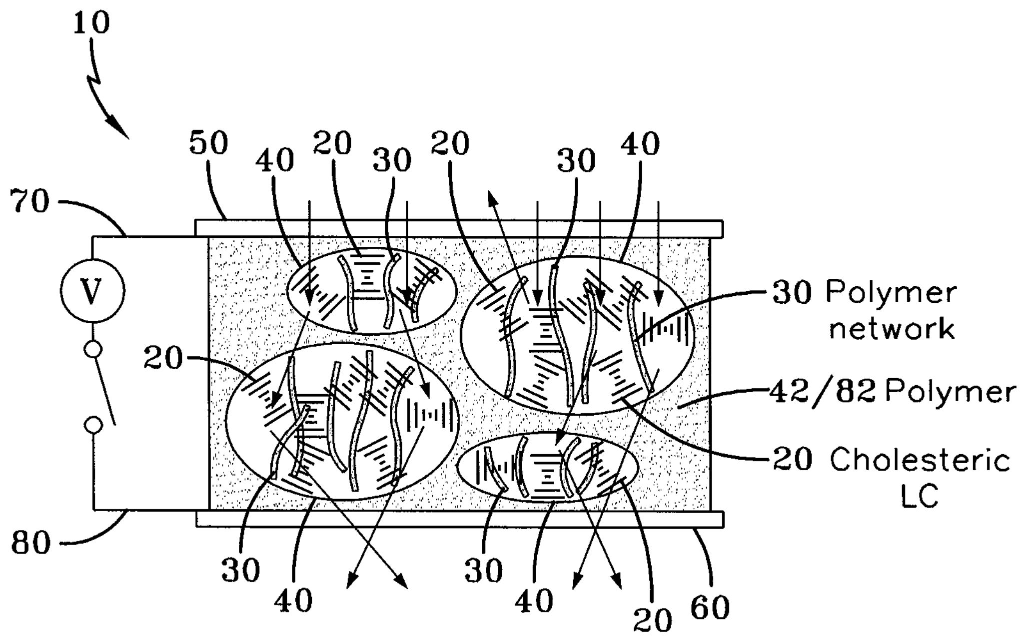
(74) *Attorney, Agent, or Firm* — Renner, Kenner, Greive, Bobak, Taylor & Weber

(57) **ABSTRACT**

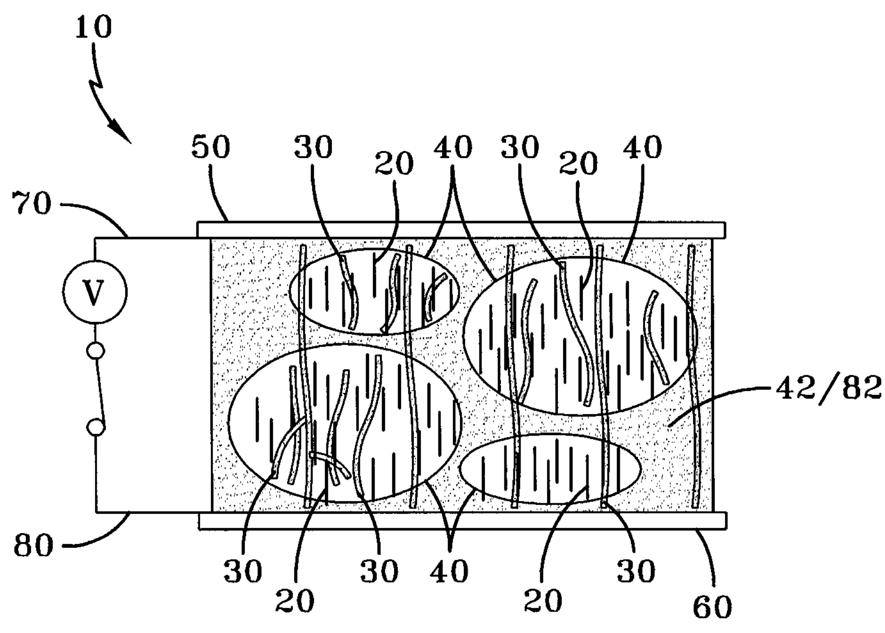
An encapsulated polymer stabilized cholesteric texture (EP-SCT) light shutter is formed from a cholesteric liquid crystal and monomer that is encapsulated into micron sized, polymer-coated droplets by either an emulsification or phase separation process. The polymer-coated droplets are disposed between transparent electrodes, where they are irradiated by ultra-violet (UV) light to polymerize the monomer.

**4 Claims, 4 Drawing Sheets**

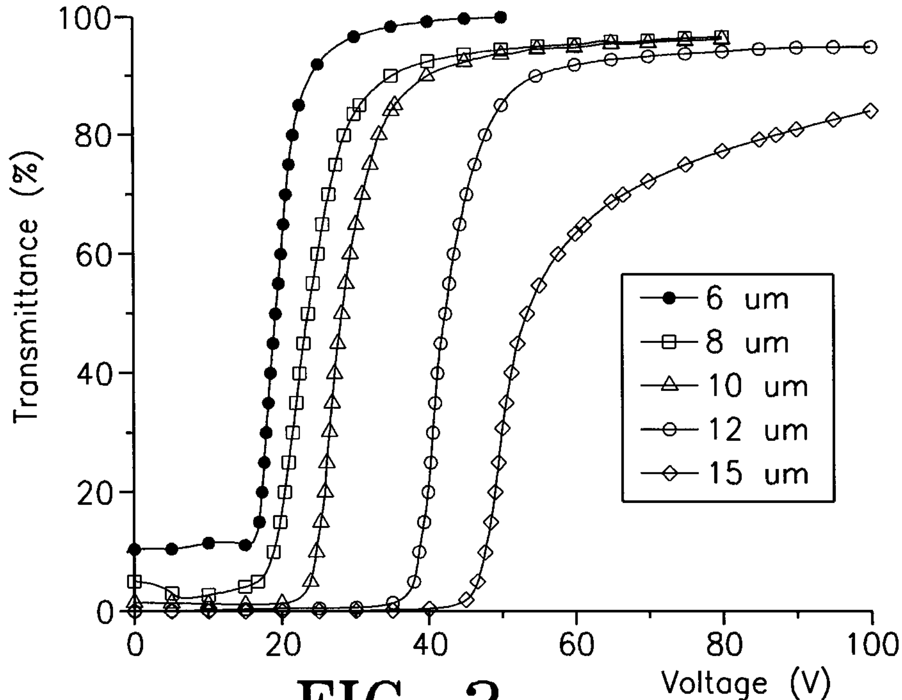



10
50
40
20
30
20
30
40
70
V
20
30 Polymer network
42/82 Polymer
20 Cholesteric LC
80
30
40
30
40
20
60

FIG–1a

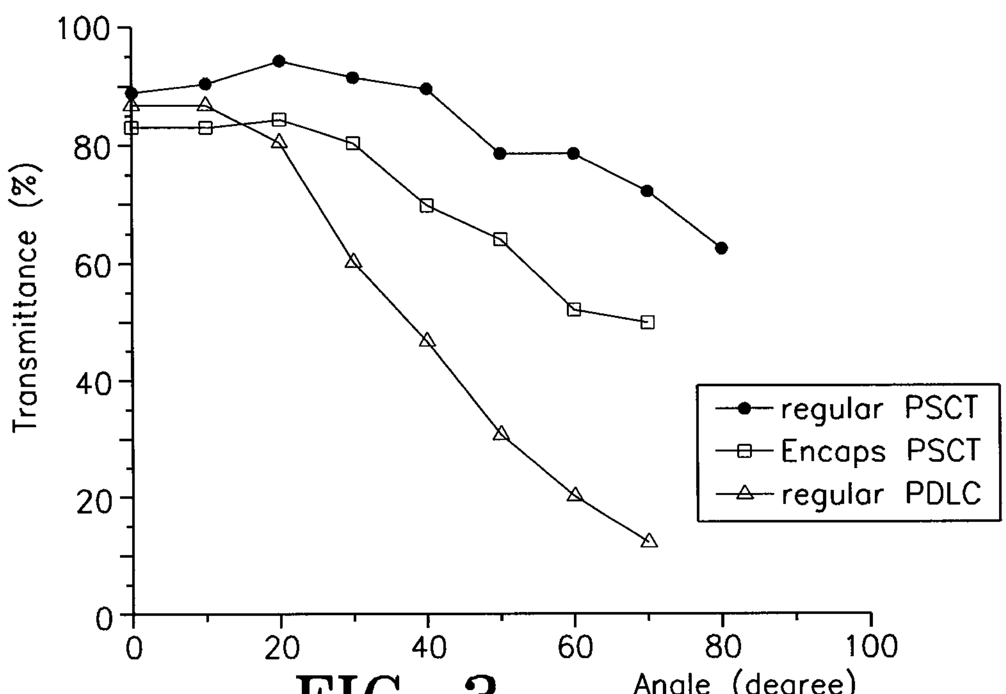

10
50
30
20
40
30
20
40
70
V
42/82
80
30
20
30
40
20
30
60

FIG–1b



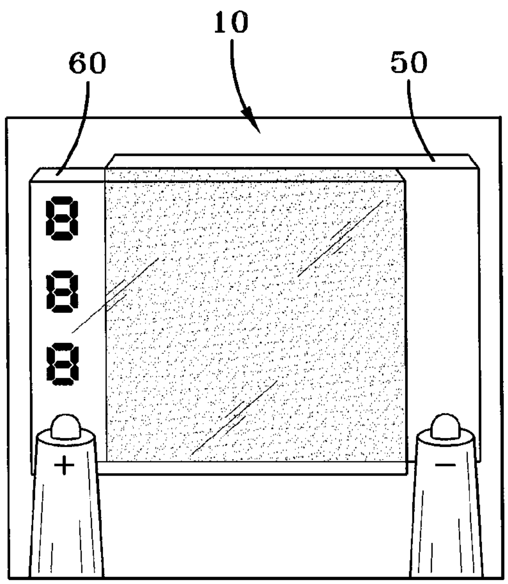
100
80
60
40
20
0
Transmittance (%)
0
20
40
60
80
100
Voltage (V)
6 um
8 um
10 um
12 um
15 um


FIG-2

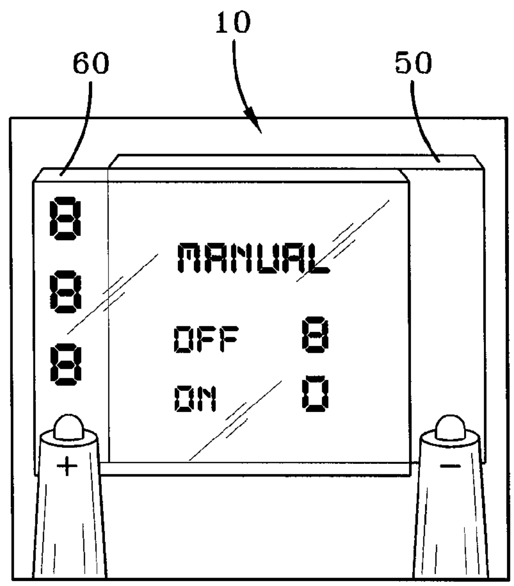


100
80
60
40
20
0
Transmittance (%)
0
20
40
60
80
100
Angle (degree)
regular PSCT
Encaps PSCT
regular PDLC

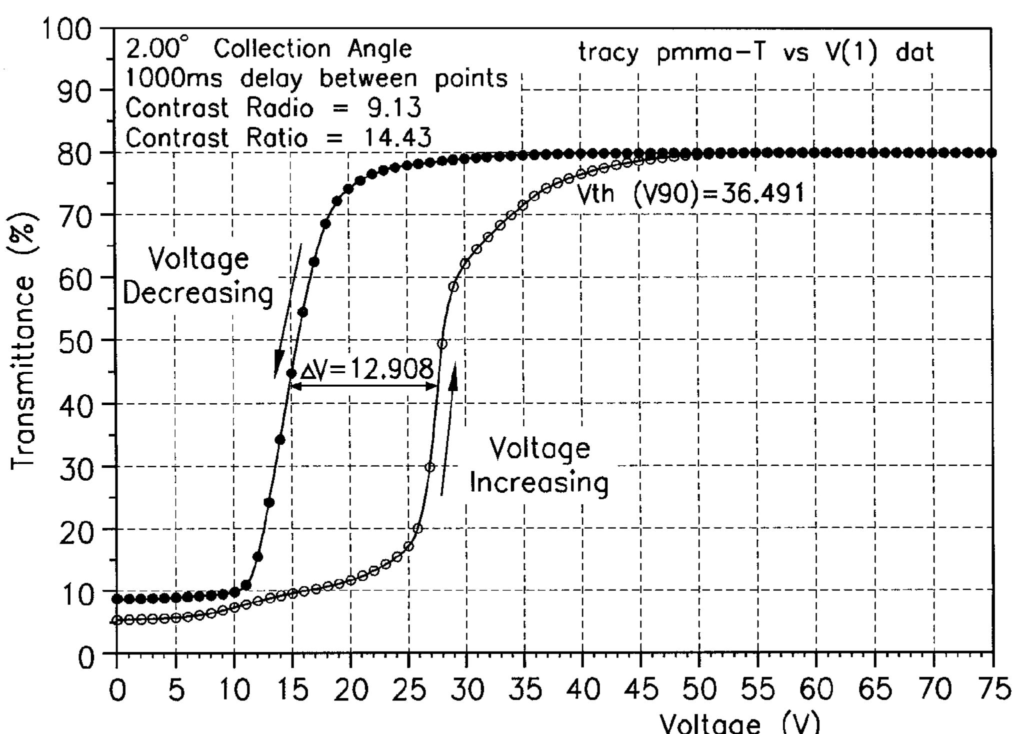

FIG-3




FIG−4a




FIG−4b




FIG−5

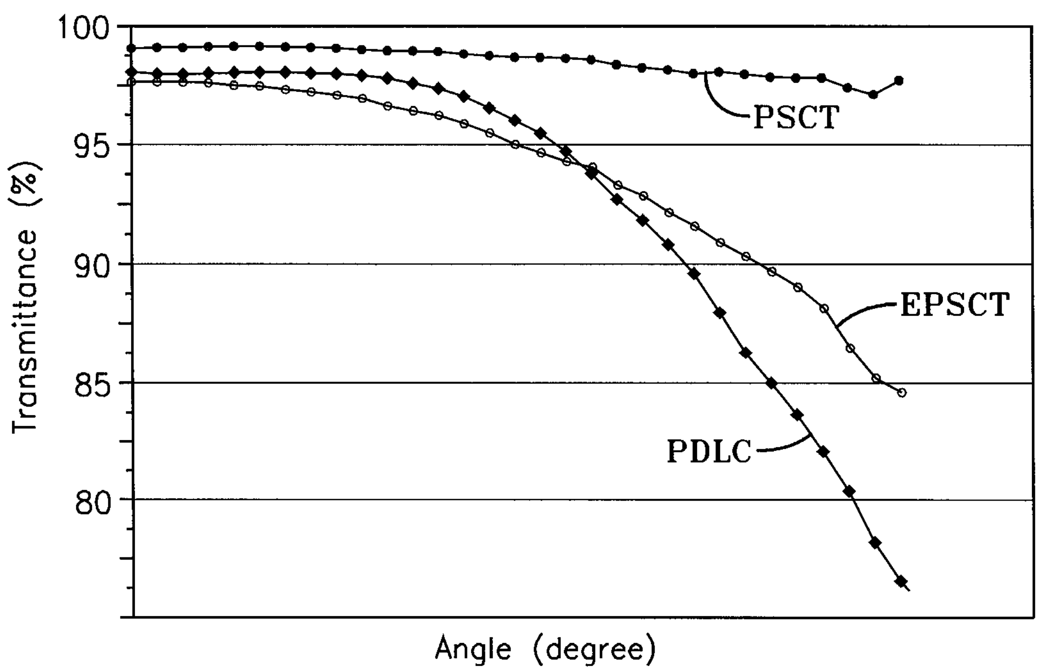



FIG-6

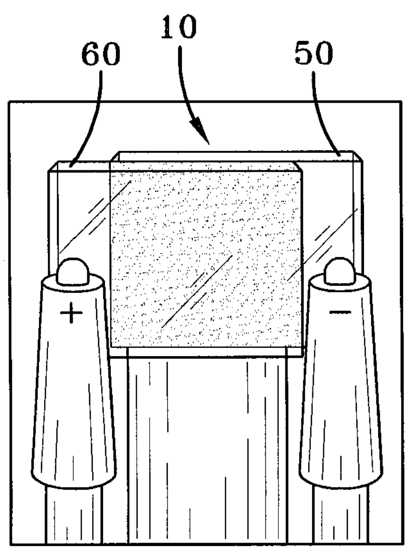



FIG-7a

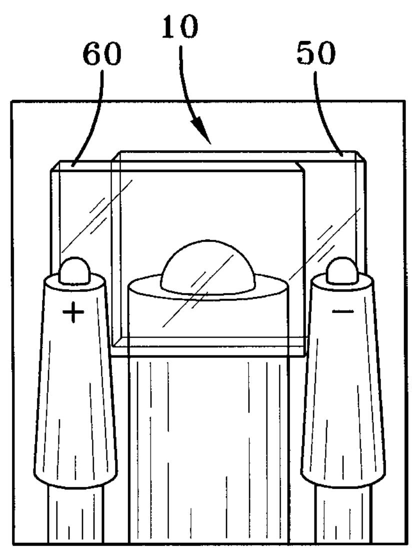



FIG-7b

# ENCAPSULATED POLYMER STABILIZED CHOLESTERIC TEXTURE LIGHT SHUTTER

## CROSS-REFERENCE TO RELATED APPLICATION

This application claims the benefit of U.S. Provisional Application No. 61/654,148 filed on Jun. 1, 2012 the contents of which are incorporated herein by reference.

## TECHNICAL FIELD

The present invention generally relates to liquid crystal light shutters. In particular, the present invention relates to a light shutter formed of a liquid crystal/polymer composite material. More particularly, the present invention relates to a light shutter formed of a liquid crystal/polymer composite material that is encapsulated into droplets, which allows the light shutter to be highly transparent and have a large viewing angle.

## BACKGROUND

Liquid crystal/polymer composites, such as those used to form polymer dispersed liquid crystals (PDLCs) and polymer stabilized cholesteric texture (PSCT) light shutters, have been used to make flexible displays, transparent displays and switchable windows. In a PDLC, the concentrations of the polymer and the nematic liquid crystal material in the composite are comparable; however, the nematic liquid crystal exists in isolated droplets that are dispersed in the polymer, such that the droplet size is comparable to the wavelength of visible light. During operation in the voltage-off state, the liquid crystal inside the droplets orients randomly throughout the PDLC material. Thus, when light propagates through the PDLC material, the encountered effective refractive index in the liquid crystal droplet is different from the encountered refractive index $n_p$ in the polymer, causing the light to scatter through the material, and as a result, the PDLC material appears opaque. When a sufficiently high electric field is applied across the PDLC material, the liquid crystal inside the droplets is aligned uniformly along the applied field (film normal direction). Thus, in the case of normal incident light, when it propagates through the liquid crystal droplet, the effective refractive index encountered by the light propagating through the PDLC material is the ordinary refractive index $n_0$ of the liquid crystal, which is matched to the refractive index $n_p$ of the polymer. As a result, the light is permitted to be transmitted through the PDLC material causing it to become transparent.

In a polymer stabilized cholesteric texture (PSCT) light shutter, the polymer concentration of the composite material is usually less than 5%, and it exists in the form of anisotropic networks, which are dispersed in a cholesteric liquid crystal. The liquid crystal exists in domains with a size comparable to the wavelength of visible light. In one voltage state, the orientation of the liquid crystals in the domains is random in the PSCT material, such that the refractive index changes from domain to domain resulting in a material that is light scattering. In another voltage state, the liquid crystals in domains are uniformly aligned in one direction, and as a result, the refractive index of the PSCT material does not vary, allowing the material to become transparent. Thus, the PSCT material can be switched between a light scattering state and a transparent state by applying the appropriate voltage or lack of voltage to the PSCT material.



Furthermore, polymer dispersed liquid crystals (PDLCs) are self-adhesive, can be easily manufactured by a roll-to-roll process, and may be formed to take up a large area. Unfortunately, PDLCs have a limited viewing angle because the refractive indices of the polymer and the liquid crystal are only matched for light incident on the cell (substrate) in a normal direction. In contrast, polymer stabilized cholesteric texture (PSCTs) liquid crystals have a large viewing angle, because the liquid crystal and the dispersed polymer network are aligned in the same direction in the transparent state, and because their refractive indices are matched for light incident in any direction. However, it is difficult to manufacture PSCTs using a roll-to-roll manufacturing process because of the low viscosity of the liquid crystal/monomer composite mixture.

Therefore, there is a need for an encapsulated polymer stabilized cholesteric texture (EPSCT) light shutter that is self-adhesive. In addition, there is a need for an encapsulated polymer stabilized cholesteric texture light shutter that has a large viewing angle. Furthermore, there is a need for an encapsulated polymer stabilized cholesteric texture light shutter that can be manufactured using a roll-to-roll process. Moreover, there is a need for an encapsulated polymer stabilized cholesteric texture light shutter that combines the benefits of a polymer dispersed liquid crystal (PDLC) and a polymer stabilized cholesteric texture (PSCT) device.

## SUMMARY OF THE INVENTION

In light of the foregoing, it is a first aspect of the present invention to provide a method of forming a light shutter comprising mixing a liquid crystal material with a monomer material and a polymer; encapsulating the liquid crystal material and the monomer material into one or more polymer-shelled droplets formed by the polymer by either an emulsion process or a phase separation process, whereby the droplets are disposed in the polymer; disposing the one or more polymer-shelled droplets and the polymer between a pair of conductive at least partially light transparent electrodes; and polymerizing the monomer.

It is another aspect of the present invention to provide a light shutter comprising first and second spaced electrodes, wherein at least one of the electrodes is at least partially transparent; a polymer disposed between the first and second electrodes; and at least one droplet having a shell formed of the polymer, the at least one droplet carried in the polymer, such that the at least one droplet carries a mixture of liquid crystal material and a polymerized monomer; wherein when a first voltage is applied to the first and second electrode, the liquid crystal material is placed in a light scattering state, and when a second voltage is applied to the first and second electrodes, the liquid crystal material is placed in an at least partially light transparent state.

## BRIEF DESCRIPTION OF THE DRAWINGS

These and other features and advantages of the present invention will become better understood with regard to the following description, appended claims and accompanying drawings wherein:

FIGS. **1***a-b* are schematic drawings showing the manner in which an encapsulated polymer stabilized cholesteric texture (EPSCT) light shutter is operated, whereby FIG. **1***a* shows the light shutter in a scattering state, and FIG. **1***b* shows the light shutter in a transparent state in accordance with the concepts of the present invention;

FIG. **2** is a chart showing the transmittance as a function of applied voltage for EPSCT light shutters having different film thicknesses in accordance with the concepts of the present invention;

FIG. **3** is a chart showing light transmittance as a function of the incident viewing angle of standard polymer dispersed liquid crystal (PDLC) and polymer stabilized cholesteric texture (PSCT) light shutters versus an encapsulated polymer stabilized cholesteric texture (EPSCT) light shutter of the present invention, where a voltage of 50V was applied for all measurements;

FIGS. **4***a-b* are schematic view of a photograph of a 10 μm EPSCT light shutter, such that FIG. **4***a* shows the EPSCT light shutter in a light-scattering state in the absence of voltage, and FIG. **4***b* shows the EPSCT light shutter in a transparent state when 50V is applied in accordance with the concepts of the present invention;

FIG. **5** shows a chart of light transmittance as a function of voltage applied to the EPSCT light shutter having different thicknesses in accordance with the concepts of the present invention;

FIG. **6** is a chart showing light transmittance as a function of incident viewing angle of the encapsulated polymer stabilized cholesteric texture (EPSCT) light shutter, as compared to that of a regular polymer stabilized cholesteric texture (PSCT) and polymer dispersed liquid crystal (PDLC) light shutter in the transparent state in accordance with the concepts of the present invention; and

FIGS. **7***a-b* are schematic views of photographs of the EPSCT light shutter, whereby FIG. **7***a* shows the EPSCT light shutter in a light-scattering state in the absence of an applied voltage, and FIG. **7***b* shows the EPSCT light shutter in a transparent state when 50V is applied thereto in accordance with the concepts of the present invention.

## DETAILED DESCRIPTION OF THE INVENTION

### I. Operation of the Encapsulated Polymer Stabilized Cholesteric Texture (EPSCT) Light Shutter

An encapsulated polymer stabilized cholesteric texture (EPSCT) light shutter **10** is fabricated in two processing steps. In a first step, a cholesteric liquid crystal **20** and a monomer material **30** that is polymerized at a subsequent time in the process as a polymer network are encapsulated into droplets **40** having a size of about 10 μm, as shown in FIG. **1** of the drawings. It should be appreciated that this encapsulation process may be achieved through either an emulsification method, a phase separation method or by any other suitable method.

In the emulsification method, the liquid crystal material **20** and the monomer material **30** are mixed with water and a water-soluble polymer **42**, or other suitable polymerizing initiator. The mixture is then stirred to form shelled droplets, whereby the polymer forms the shell of the droplet, while the liquid crystal **20** and the monomer material **30** are disposed inside the droplets **40**. In one aspect, various agents may be added to the mixture to stabilize the droplets **40**. The encapsulated material is then sandwiched or otherwise disposed between two substrates **50** and **60** with transparent electrodes **70** and **80**.

In the phase separation method, the liquid crystal material **20** and monomer material **30** are combined with a thermoplastic polymer **82**, or other suitable polymerizing initiator. The mixture is then sandwiched or otherwise disposed between two at least partially transparent substrates **50**,**60** with transparent electrodes **70**,**80** that are configured to be coupled to any suitable voltage source "V", such as an AC (alternating current) or DC (direct current) voltage source. When the combined material is heated to a high temperature, the polymer **42**, the liquid crystal **20** and the monomer material **30** are uniformly mixed to form a mixture. When the mixture is cooled, the liquid crystal **20** and the monomer material **30** phase separate from the polymer **82** to form polymer shelled droplets **40**. That is, the droplets **40** encapsulate the liquid crystal material **20** and the monomer material **30** in a polymer shell. It should also be appreciated that the substrates **50**,**60** and corresponding transparent electrodes **70**,**80** used to form the light shutter **10** may be combined, such that substrates **50**,**60** form electrically conductive electrodes. In a further aspect, it should be appreciated that either or both of the substrates **50**,**60** and that either or both of the electrodes **70**,**80** may be at least partially transparent.

In a second step of forming an encapsulated polymer stabilized cholesteric texture (EPSCT) light shutter **10** using either of the emulsification or phase separation method, the monomer material **30** is polymerized under UV irradiation in the homeotropic texture in the presence of an externally-applied electric field. The liquid crystal **20** has a positive dielectric anisotropy and tends to align parallel to the applied electric field. The formed polymer network **30** is anisotropic and perpendicular to the cell substrate and divides the liquid crystal **20** into domains with a size comparable to the wavelength of visible light.

The operation of the encapsulated polymer stabilized cholesteric texture (EPSCT) light shutter **10** is shown in FIG. **1** of the drawings. Specifically, in the absence of an electric field, the liquid crystals **20** are placed in the poly-domain focal conic texture, as shown in FIG. **1***a*, such that the refractive index is varied in space causing the EPSCT material to be highly light scattering. The scattering of light is mainly caused by the abrupt refractive index change between the domains of the liquid crystals **20**. When a sufficiently high voltage is applied across the EPSCT cell **10**, as shown in FIG. **1***b*, the helical structure of the liquid crystals (with $\Delta\in>0$) is unwound, and the liquid crystals **20** are uniformly aligned parallel to the polymer network **30**, thus causing the EPSCT light shutter **10** to become transparent.

It should be appreciated that the light shutter **10** of the present invention may serve as a single cell, which is combined in a matrix of a plurality of similar cells to form a larger overall light shutter. Alternatively, the components of the light shutter **10** may be configured to take on any desired dimension and suitable shape.

### II. Experimental Results

#### Example 1

#### Emulsification Method

During the formation of the encapsulated polymer stabilized cholesteric texture (EPSCT) light shutter **10** using the emulsification method, water-soluble Polyvinyl Alcohol (PVA) was used, such that the concentrations of the materials were about: 46% water; 8.1% PVA; 2.7% surfactant; and 43.2% liquid crystal/monomer mixture. The solution was placed into a bottle and stirred by spinning a magnet carried inside the bottle. The spinning speed of the magnet was one of the factors controlling the droplet size, and as such, the spinning speed was set at about 500 RPM (revolutions per minute). The stirring time was about 15 seconds, and the liquid crystal/monomer mixture was emulsified into droplets having a size of about 10-20 μm.

The emulsion may be coated on either a glass plate or on PET (polyethylene terephthalate) film with ITO (indium-tin-oxide) electrodes. A doctor blade was used in the coating process to produce a uniform film thickness without breaking the droplets. The emulsion was allowed to dry in air for several hours. In addition, a second substrate was laminated on the top of the emulsion. In one aspect, heating the emulsion may be performed to soften the material to assist its adherence to the top substrate.

In the final dried emulsion, the concentration of the liquid crystal/monomer was about 80%. The cholesteric liquid crystals (LCs) were made from nematic E44 liquid crystal material and chiral dopant R811 material, while the monomer comprised RM257 material, which is bi-functional. The pitch of the cholesteric liquid crystals were about 1 μm, and the ratio between the liquid crystals and the monomer was about 97:3. A very small amount of photo-initiator was also added into the mixture before the emulsification process was carried out. During the UV (ultra-violet light) curing process, a sufficiently high voltage was applied across the encapsulated polymer stabilized cholesteric texture (EPSCT) light shutter, such that the mixture was in the homeotropic texture where the helical structure of the liquid crystals were unwound, such that the liquid crystals became aligned in the cell normal direction. The formed polymer network was anisotropic and in the same direction as the liquid crystal during the polymerization. The UV intensity was 10 $mW/cm^2$, and the curing time was about 30 minutes.

The light transmittance of the encapsulated polymer stabilized cholesteric texture (EPSCT) light shutter **10** at various thicknesses (such as 6, 8, 10, 12, and 15 um for example), as a function of the applied voltage is shown in FIG. **2**. Specifically, in the absence of an applied voltage, the light shutter **10** is placed in a light-scattering state, whereby its light transmittance is low. Alternatively, when the voltage applied to the light shutter **10** is increased, the light transmittance of the light shutter **10** increases. Finally, when sufficiently high voltages are applied to the EPSCT light shutter **10** of the present invention, the light shutter **10** is switched to a substantially transparent state, where its light transmittances are high.

In addition, the encapsulated polymer stabilized cholesteric texture (EPSCT) light shutter **10** of the present invention was able to achieve a large viewing angle, which is a major advantage over polymer dispersed liquid crystal (PDLC) devices. To conduct the measurement, a 10 μm thick EPSCT film **10** was immersed in glycerol (whose refractive index matching with glass) contained in a glass cylinder. The EPSCT light shutter **10** was then rotated to change the light incident angle. For comparison with the EPSCT light shutter **10**, the viewing angle of a regular polymer dispersed liquid crystal (PDLC) and a regular polymer stabilized cholesteric texture (PSCT) light shutter were measured. The regular PSCT sample light shutter was made from the same mixture as the EPSCT light shutter **10** of the present invention and cured under the same conditions. The regular PDLC sample was made from polyvinyl alcohol (PVA) and E44 emulsion with much smaller droplets (<1 μm), and coated with the same procedure as the EPSCT light shutter **10** of the present invention. Both the regular PDLC light shutter and the regular PSCT light shutter (control shutters) also had a film thickness of 10 μm. The light transmittance of the regular PDLC and regular PSCT light shutters, and the EPSCT light shutter **10** in the transparent state as a function of the incident angle is shown in FIG. **3**. Specifically, FIG. **3** shows that the EPSCT light shutter **10** of the present invention had a much better viewing angle than the regular PDLC light shutter.

Continuing, schematic views of the encapsulated polymer stabilized cholesteric texture (EPSCT) light shutter **10** of the present invention are shown in FIGS. **4***a-b*. Specifically, when no voltage was applied, the light shutter **10** is placed in a light-scattering state, and appeared milky in color, such that it blocked the scene/image that was located behind the EPSCT light shutter **10**, as shown in FIG. **4***a*. When a voltage with an amplitude of 50 V was applied, the EPSCT light shutter **10** was switched to a transparent state, whereby and the scene/image that was located behind the EPSCT light shutter **10** was able to be seen as shown in FIG. **4***b*.

Example 2

Phase Separation Method

In the phase separation method of forming the light shutter **10**, a cholesteric liquid crystal and monomer were mixed with a polymer, such as poly(methyl methacrylate) (PMMA). The concentration of PMMA was about 20% and the concentration of the liquid crystal and monomer material was about 80%. The liquid crystal/monomer mixture comprised about 83.7% nematic liquid crystal E44, about 13.0% chiral dopant R811, about 3.0% monomer R.M257 and about 0.3% photo-initiator BME (benzoin methyl ester). The liquid crystal, monomer and polymer were mixed and sandwiched between two glass substrates and transparent indium-tin-oxide (ITO) electrodes to form the encapsulated polymer stabilized cholesteric texture (EPSCT) light shutter **10**. Moreover, the thickness of the thickness of the light shutter **10**, defined by the space between the pair of electrodes/substrate, was about 20 μm. In addition, the light shutter **10** was heated above about 120° C. and then cooled down to room temperature at the cooling rate of about −0.1 degree/minute. Finally, the light shutter **10** was placed under ultra-violet (UV) light to polymerize the monomer. Thus, when sufficiently high voltages were applied, the light shutter **10** was switched to a transparent state, and whereupon its light transmittances became high. It should also be appreciated that the light shutter formed using the phase separation method also achieved a large viewing angle. Moreover, FIG. **5** shows the light transmittance of the encapsulated polymer stabilized cholesteric texture (EPSCT) light shutter **10** for varying applied voltages.

Next, the light transmittance of the EPSCT light shutter **10** of the present invention in the transparent state as a function of the light incident angle was also evaluated, as shown in FIG. **6** of the drawings. As such, the EPSCT light shutter **10** achieved a better viewing angle than the regular PDLC light shutter.

In addition, schematic views of photographs of the encapsulated polymer stabilized cholesteric texture (EPSCT) light shutter **10** are shown in FIGS. **7***a-b* of the drawings. Specifically, when no voltage was applied, the EPSCT light shutter **10** was in the light scattering state, and appeared milky, so as to block the scene/image located behind the light shutter **10**, as shown in FIG. **7***a*. When a voltage with an amplitude of 50 V was applied, the EPSCT light shutter **10** of the present invention was switched to the transparent state and the scene or image disposed behind the light shutter **10** was able to be seen therethrough by a viewer, as shown in FIG. **7***b*.

Therefore, one advantage of an encapsulated polymer stabilized cholesteric texture (EPSCT) light shutter of the present invention is that it is self-adhesive and can be manufactured in a roll-to-roll process. Another advantage of the encapsulated polymer stabilized cholesteric texture (EPSCT) light shutter in that it has a highly transparent state and large viewing angle. Still another advantage of the encapsulated polymer stabilized cholesteric texture (EPSCT) light shutter of the present invention is that it can be used for various applications, including flexible displays, switchable privacy windows, and energy-saving architectural windows, which is highly desirable.

Thus, it can be seen that the objects of the invention have been satisfied by the structure and its method for use presented above. While in accordance with the Patent Statutes, only the best mode and preferred embodiment has been presented and described in detail, it is to be understood that the invention is not limited thereto or thereby. Accordingly, for an appreciation of the true scope and breadth of the invention, reference should be made to the following claims.

What is claimed is:

**1**. A light shutter comprising:

first and second spaced electrodes, wherein at least one of said electrodes is at least partially transparent;

a polymer disposed between the first and second electrodes; and

at least one droplet having a shell formed of the polymer, wherein said polymer shell fully encapsulates a polymer network dispersed in liquid crystal material;

wherein when a first voltage is applied to the first and second electrode, the liquid crystal material is placed in a light scattering state, and when a second voltage is applied to the first and second electrodes, the liquid crystal material is placed in an at least partially light transparent state.

**2**. The light shutter of claim **1**, wherein said first and second electrodes are formed of indium-tin-oxide (ITO).

**3**. The light shutter of claim **1**, wherein the liquid crystal material comprises nematic liquid crystals.

**4**. The light shutter of claim **1**, wherein the liquid crystal material is anisotropic.

* * * * *